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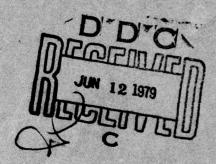


A METHODOLOGY FOR CROSS SECTION ANALYSIS AND LIQUID WATER CONTENT ASSESSMENT AT KWAJALEIN

Allan J. Bussey

Environmental Research & Technology, Inc. 696 Virginia Road Concord, Massachusetts 01742

July 1978



Scientific Report No. 2

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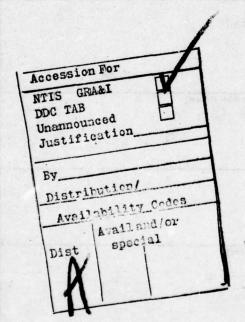
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as input for a determination of the erosion severity index (ESI). The advantage

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# 20. ABSTRACT (cont)

of the techniques described is that estimates or a climatology of ESI can be obtained in any part of the world through an analysis of readily available meteorological observations.



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V

# A METHODOLOGY FOR CROSS SECTION ANALYSIS AND LIQUID WATER CONTENT ASSESSMENT AT KWAJALEIN

The method of analysis used for Kwajalein Island has been developed over several years by scientists at the Air Force Geophysics Laboratory (AFGL) and Environmental Research & Technology, Inc. (ERT). This report is geared to the cross-section analysis and liquid water content (LWC) assessment of Kwajalein Island but a similar methodology can be applied to all regions of the world. The Erosion Severity Index (ESI) can be obtained from the estimates of LWC.

#### 1. PREPARATION OF CROSS-SECTIONS

## 1.1 Meteorological Tools Needed in the Analysis

The meteorological data available for the calendar year 1975 at Kwajalein Island was very good. The weather station at Kwajalein submitted 6-hour synoptic reports, intermediate airways reports on the hour with special reports on the minute, radar weather observations (RAOBS), and daily radiosondes. These reports were supplemented by DMSP satellite images four times daily over the Kwajalein Island area. More frequent upper air soundings, in the order of four times daily or every six hours, would have been helpful in the analysis, but Kwajalein's location in an area where the atmosphere changes little from day to day and season to season meant that daily soundings were generally sufficient. All the meteorological data sets were used in the analysis since final assessment of LWC (liquid water content) would have decreased in reliability had any one of them been unavailable.

#### 1.2 Plotting Meteorological Data

The meteorological data was drawn on a chart specifically designed to fit the type of atmosphere found over Kwajalein Island (Figure 1-1). The chart size used was 17 x 22 inches which is a standard size of blue-line ozalid paper. The vast majority of clouds and precipitation occur in the troposphere, therefore, the height of the tropopause (the upper boundary of the troposphere) was the determining factor in the height of the cross-section. Kwajalein Island, located at 08:44 N, has an average tropopause height of 16 to 17 km, therefore, charts with a height scale

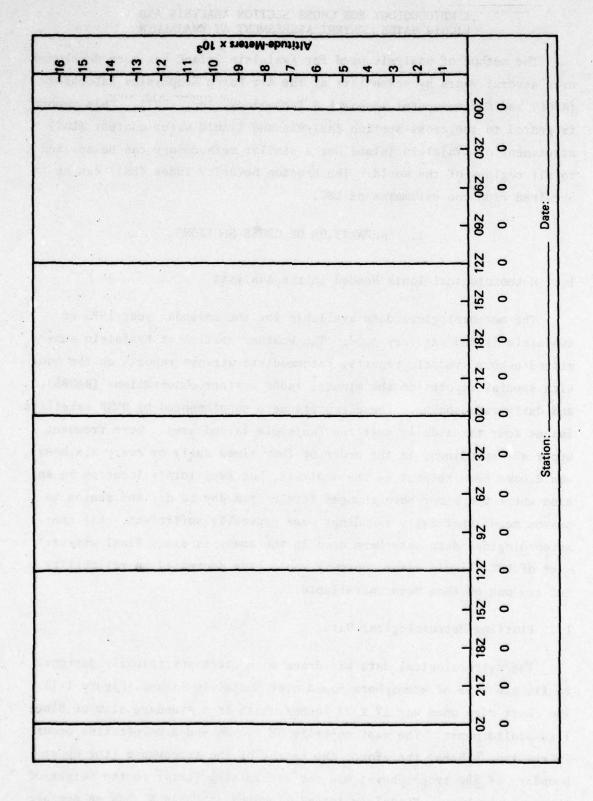


Figure 1-1 Cross-Section Analysi Chart

of 17 km were used. The vertical dimension of the chart was determined by the number of observations which had to be plotted along the radio-sonde path length, represented by a straight vertical line on the chart, up to the 17 km level. The horizontal dimension of the chart was determined by the number of surface observations and upper air soundings to be plotted. Since there were upper air soundings every 24 hours, instead of the customary 6 hours, 48 hours of met data was plotted on each cross-section, conserving both storage space and material.

The 6-hour synoptic reports were plotted on the cross-section in the spaces provided using the standard Weather Bureau model (Figure 1-2). The airways reports were plotted on either side of the synoptic reports giving a plotted report for each 3-hour period (Figure 1-3). In addition, the airways special reports, which indicate abrupt changes in weather, were added between the regular reporting times to give further information concerning the type of precipitation occurring, when it started, or when it ended (Figure 1-3).

The surface data for Kwajalein was printed in a different format from the customary 5-digit grouping received on Service "C" teletype (Figure 1-4). All the mandatory meteorological data was contained in this message and, in fact, it contained better than usual information on cloud bases giving hourly reports on estimated low, middle and high cloud bases. These estimated base heights, given under word 8 on the printout, were extremely helpful in the analysis. A problem did occur, however, when it was discovered that the rainfall amounts, given under word 13, were not always converted from inches to mm. Group 7, in the remarks column, always recorded rainfall in inches (hundreths) and this source of information was used to correct the erroneous word 13 values. Literature is available which explains in detail the meteorological data shown in Figure 1-4. Most of the data is self-explanatory.

The upper air data was plotted using the height given on the radiosonde report with the air temperature (°C) to the left of the vertical line and the dew point depression (air temperature minus dew point temperature) to the right of the line. The wind values were placed along side the temperature values to retain the readability of the temperature values.

Symbolic Station Model

Sample Plotted Report

#### Where:

N = Total Amt. of Cloud = 10/10

dd = Direction from which Wind is Blowing = SE

ff = Wind Speed in Knots = 3-7

VV = Visibility in km = 24

WW = Present Weather = Precip. in Sight but not at Station

W = Past Weather = Shower

PPP = Sea Level Pressure in mb = 1010.8

TT = Air Temp. in °C = 27.8

N<sub>h</sub> = Fraction of Sky Covered by Low Cloud = 3/10

CL = Low Cloud Type = CB without Anvii

h = Height of Base of Cloud = 300-600 Meters

CM = Middle Cloud Type = Ac formed from Cu

CH = High Cloud Type = Cirrostratus

 $T_d T_d = Dewpoint Temp. in °C = 23.9$ 

PP = 3 Hr. Pressure change in MB = 0.5

a = Characteristic of Baragraph Trace = Falling then Steady

RR = Amount of Precip. over past 6 Hrs. = 2 MM

[Ref. Federal Meteorological Handbook

No. 2, 1969]

Figure 1-2 U.S. Weather Bureau Plotting Model

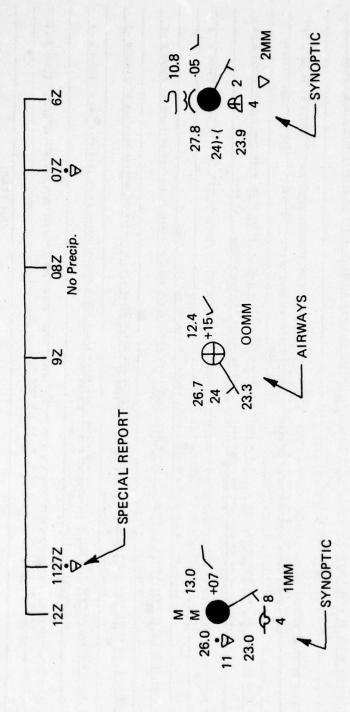


Figure 1-3 Method Used in Plotting Synoptic and Airways Data for Kwajalein Island

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[Ref ETAC]

Figure 1-4 Sample of Kwajalein Surface Data

#### 2. CROSS-SECTION ANALYSIS

There are five tasks involved in analyzing a cross-section. These are: locating the tropopause, drawing certain "key" isotherms, depicting boundary layers or fronts, drawing certain "key" lines of equal dew point depression, and sketching in clouds and precipitation areas.

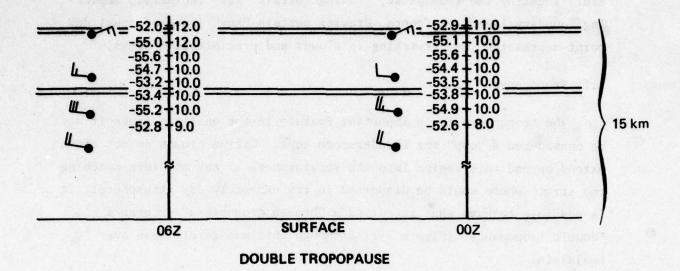
# 2.1 Tropopause

The tropopause is an important feature in the analysis since it may be considered a "cap" for thunderstorm tops. Cirrus clouds do not often extend beyond this region into the stratosphere as any moisture reaching the stratosphere would be dispersed in its extremely dry atmosphere. It is possible to have what is called a "broken tropopause" or even a "double tropopause" (Figure 2-1) although this was rarely seen over Kwajalein.

In mid-latitudes the tropopause is most often found in the region of maximum winds, especially during winter months. It is also denoted by a significant change in the thermal lapse rate showing a change from decreasing temperature values with increasing height to a more stable or increase of temperature values with height. A change in wind direction of greater than 90° is often another characteristic of the tropopause region. These factors are generally enough to determine the placement of the tropopause although in the tropics wind speed plays a lesser role.

#### 2.2 Isotherms

In the assessment of precipitation LWC, it is necessary to determine the boundary lines of rain, large snow, small snow and ice crystals defined by the 0°C, -15°C and -30°C isotherms on the cross-section. Where precipitation is occurring, it will be in the form of rain in the region where the temperature is greater than 0°C, large snow in the region between 0°C and -15°C, small snow in the region between -15°C and -30°C and it will be in the form of ice crystals in the region where the temperature is -30°C or lower. There may be some "over-lapping" in these areas, especially in the case of ice crystals which can be found at temperatures as high as -25°C but these layers represent very good standards to be used in the analysis.



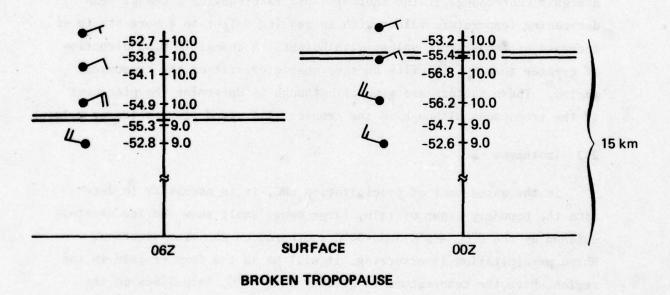


Figure 2-1 Examples of Locating the Tropopause Layer

#### 2.3 Fronts

Fronts often act as boundaries for clouds (moisture) and are an important feature in mid-latitude cross-section analysis. However, they were not important in the Kwajalein Island cross-section analysis since frontal activity is virtually non-existent in the tropics. Fronts are stable layers forming boundaries between warm (moist) and cold (dry) air (Figure 2-2). They are represented on the cross-sectin by a double line in the same manner as the tropopause. Fictitious fronts occur due to diurnal variations in temperature but their effect on acting as a boundary for clouds remains the same and they should be taken into account in the analysis.

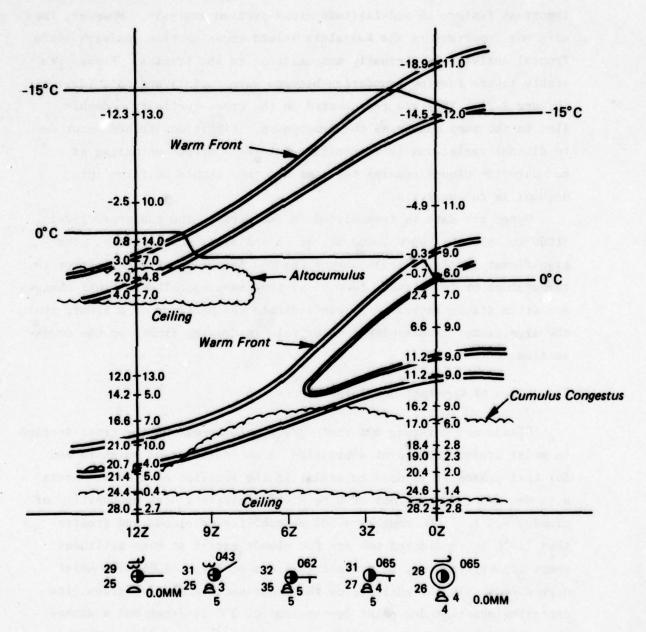
Upper air data is transmitted in two parts: the mandatory levels (1000 mb, 850 mb, 700 mb, 500 mb, etc.) and significant levels. The significant levels indicate abrupt changes in the lapse rate, either in temperature or in moisture (dew point temperature). These abrupt changes are often stable layers which can indicate the presence of a front, thus the significant levels play a major role in drawing fronts on the cross-section.

# 2.4 Lines of Constant Dew Point Depression

Clouds are moisture and therefore should appear on the cross-section in moist areas. Dew point depression is an indicator of moisture and for that reason it is used to assist in the location of clouds. Areas with dew point depressions of 0 to 3.0°C indicate a high probability of clouds, 3.0 to 7.0°C roughly a 50% probability of clouds and greater than 7.0°C is considered too dry for clouds except at high altitudes where ice crystals may be present in areas of large (10°C) dew point depressions. In the analysis of the cross-section a solid green line depicting constant dew point depressions of 3°C is drawn and a dashed green line depicting constant dew point depressions of 7°C is drawn. From these lines, moist and dry areas are determined.

#### 2.5 Clouds and Precipitation

The first step in sketching a cloud on the cross-section is to locate the base of the cloud. The synoptic report gives estimated bases



\*Data taken from Hong Kong analysis 1 July 1973.

Figure 2-2 Use of Frontal Analysis in Locating Clouds

of clouds and is particularly accurate in the lower levels for cloud types such as stratocumulus and cumulus. In middle and high altitudes where errors in estimates may be larger, moist areas are used to determine the cloud base. A general knowledge of cloud types is also helpful in drawing cloud bases as certain types of clouds are only found in certain regions of the atmosphere.

The top of the cloud is also determined by the moisture pattern. Where there is a lack of upper air data the cloud analysis suffers but in the case at Kwajalein, the lack in upper air data was offset by RAOB reports which gave the tops of clouds as seen on radar. The RAOB report is the most accurate means of determining the cloud tops but it must be remembered that small particles, such as ice crystals, may not be sensed by the radar. As was discussed earlier, the tropopause is used to place a limit on the vertical extent of cloud formations (cirrus) and fronts also indicate boundaries in cloud extent (see Figure 2-2). In the case where there is no RAOB report or estimated height, the intensity of the precipitation will indicate what general type of cloud is present and an "educated" guess can be given on the cloud height.

In the final assessment of LWC, the amount or coverage of the cloud and precipitation is needed. The surface observations, both airways and synoptic, usually give cloud amounts (see Figure 1-4) but when this is not the case, the cloud and precipitation amounts are determined by looking at the past weather, the precipitation amounts and nephanalysis of satellite images. The past weather can be used to determine whether the system is showery or uniform in nature. If there was no precipitation reported, nephanalysis will give a wide coverage of the type and amount of clouds being advected over the station. In determining the amount of precipitation, it is assumed that the entire cloud is precipitating. When there is more than one cloud, the most probable precipitator is chosen, although it is possible to have more than one cloud precipitating, for example, a cumulo-nimbus (thunderstorm) in a nimbostratus system.

#### 3. LWC ASSESSMENT

## 3.1 Types of LWC

LWC values are determined for clouds and precipitation. Precipitation LWC is broken down into rain, large snow, small snow and ice crystals. Cirrus clouds which are made up of ice crystals are categorized under precipitation.

## 3.2 Assessing Cloud LWC

Cloud LWC is determined by the type of cloud, the atmosphere that the cloud is in, the thickness of the cloud and the physical characteristics of the cloud, that is, whether it is growing, precipitating or decaying. Scientists at AFGL performed intensive research into the problem of assessing cloud LWC and compiled extensive data on cloud water content. Tables A-1 to A-10 which were used in assessing LWC values for Russia, list the work of Russian cloud physicists such as Borovikov, Shatskiz, Nikondrova and Chuvaev who determined water contents based on cloud types, their thickness and the atmospheric temperature in which they were found.

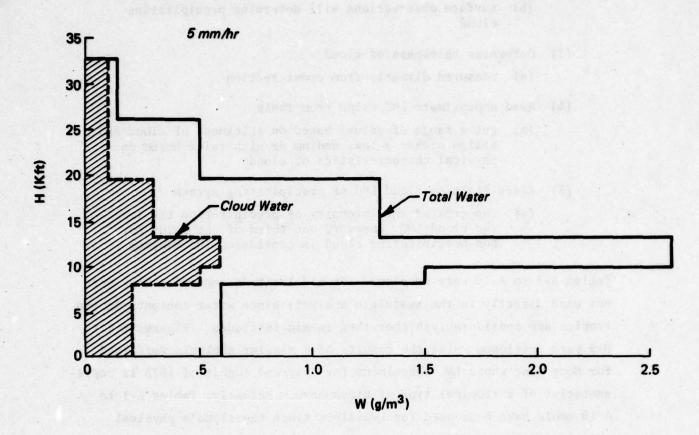
Table A-1 gives water content values for upper, middle and lower regions of a cumulus type cloud. There is a large variation in water content values between these regions and clouds of large vertical extent should be subdivided for more accuracy, but to save time and still maintain high accuracy, it was decided to use average water content values.

Figure 3-1 shows the combined cloud and precipitation LWC of a precipitating cloud system where the cloud LWC comprises only about a third of the total LWC. A precipitating cloud has less cloud LWC in it than a non-precipitating cloud of similar type and thickness and a decaying cloud has less LWC in it than a growing one. The wide range in water content values given in Tables  $\Lambda$ -1 to  $\Lambda$ -10 for the same temperature and thickness bear out this fact.

The steps involved in assessing cloud LWC are as follows:

#### (1) Determine cloud type

- (a) cloud types generally given by surface observations
- (b) if surface observations not available, use satellite photo or rely on meteorological experience



[Ref: Kapur (1970) from Davis]

Figure 3-1 Cloud and Precipitation LWC of a Precipitating System

- (2) Determine whether cloud is decaying, growing or precipitating
  - (a) the continuity of the cross-section will help in determining the physical characteristics of the cloud
  - (b) surface observations will determine precipitating cloud
- (3) Determine thickness of cloud
  - (a) measured directly from cross-section
- (4) Read approximate LWC value from Table
  - (a) get a range of values based on thickness of cloud and assign either a low, medium or high value based on physical characteristics of cloud
- (5) Place limit on cloud LWC of precipitating system
  - (a) the greater the intensity of precipitation the less the cloud LWC, however, one third of the value for a non-precipitating cloud is considered the minimum

Tables A-1 to A-10 were developed for mid-latitude regions. They were not used directly in the Kwajalein analysis since water contents in the tropics are considerably higher than in mid-latitudes. Figures B-1 to B-5 were developed using the results of a similar analysis performed for Hong Kong whose LWC assessment for July and August of 1973 is representative of a tropical type of atmosphere. Actually, Tables A-1 to A-10 could have been used for Kwajalein since the cloud's physical characteristics would have indicated choosing high LWC values from the tables and obtaining results equivalent to Figures B-1 to B-5. In future work, however, it is recommended that Figures B-1 to B-5 again be utilized since they are easier to use and will eliminate possible errors in determining the physical characteristics of tropical weather systems.

# 3.3 Assessing Precipitation LWC

Figure 3-2 is a graph (developed by AFGL) in which a relationship showing different types of precipitation as a function of rain rate vs water content is drawn. This graph has been used extensively in all analysis performed by AFGL and ERT to determine precipitation LWC.

The method used to determine precipitation LWC is as follows:

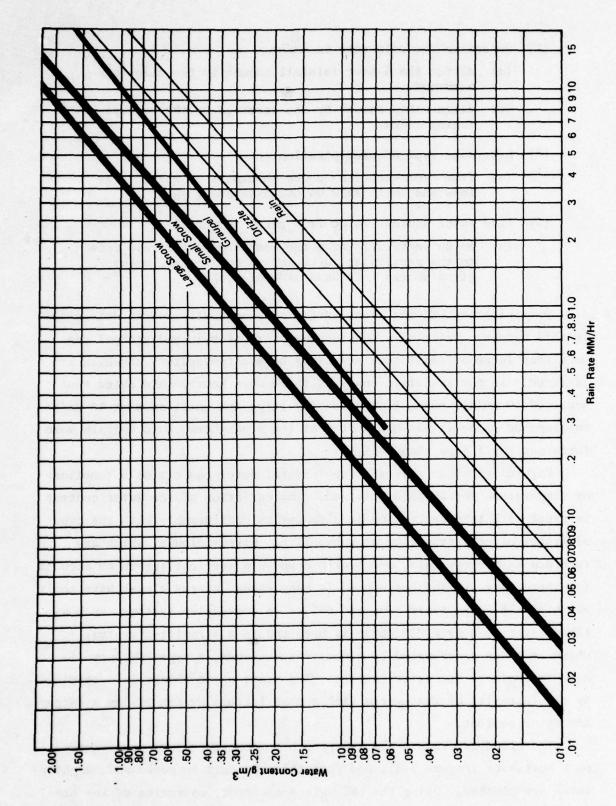


Figure 3-2 Precipitation LWC

- (1) Determine the rain rate in mm/hr
  - (a) divide the 6-hour rainfall amount by the time rain occurred
  - (b) divide this amount by the coverage of the precipitating cloud
- (2) Determine type of precipitation
  - (a) from cross-section record thickness of rain, large snow and small snow on LWC assessment sheet
- (3) Read water content value from graph (Figure 3-2)
  - (a) go up vertically from the computed hourly rain rate to the particular curve and record the LWC value given on the left hand side of graph

Precipitation LWC for rain, large snow and small snow is determined in this manner. Drizzle is considered a form of rain and graupel can be either large or small snow depending on the temperature at which it is found. In the Kwajalein analysis there were hourly rain rates that exceeded 10 mm/hr, but a limitation for large and small snow at 10 mm/hr was imposed since it was not felt that the atmosphere could contain more large and small snow than this.

Figure 3-3 shows curves of ice crystal water content as a function of temperature for Kwajalein Island. The variation of ice water content is great with temperature and it also varies considerably with the type of system either stratified or convective. Cirrus clouds, which are recorded as ice crystals, are broken down into vertical layers to account for these large variations since, in many cases, cirrus clouds have their bases at -28°C and their tops at -65°C. In convective systems, such as thunderstorms, a type "A" curve is used and in a stratified system, which is often accompanied by nimbostratus clouds, a type "B" curve is used to evaluate ice water content. The exact curve chosen is determined by the intensity of the system with a more intense system giving a larger ice water content.

The cloud LWC values and the precipitation LWC values are recorded on a worksheet (Figure 3-4), and from this the data is coded and computer cards are punched. Using the LWC values as input, estimates of the erosion severity index are calculated and appropriate climatologies can then be derived.

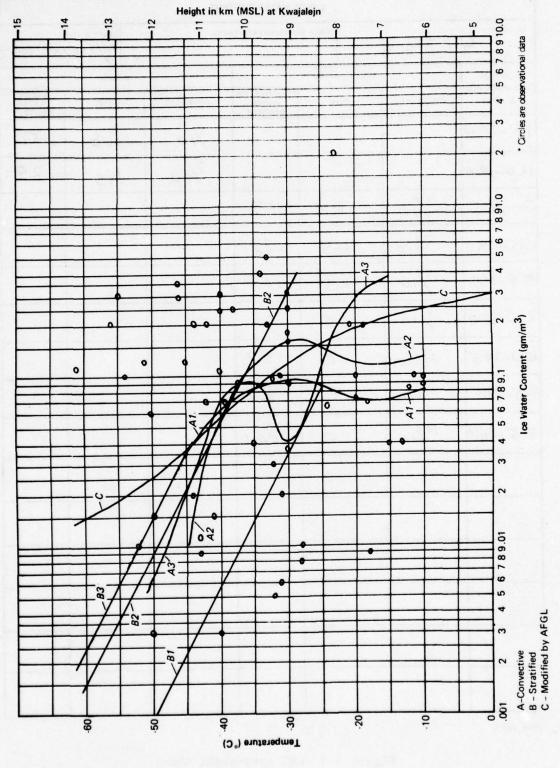


Figure 3-3 Ice Crystal Precipitation LWC

		LIQUI	D WATER CONT	ENT		
LOCATION 9	1366	10/21/	75-06 T			
ALTITUDE		PRECIPITATION			CLOUD	
OF FEET	COVERAGE	TYPE	PRECIPITATION WATER CONTENT	COVERAGE	TYPE	LIQUID WATER CONTENT
1.5-30.0				1/10	СЬ	1.50
12.0-19.0				7/10	Ns	.24
0-15.5	7/10	RN	.07			
15.5-19.0	7/10	LS	. 33			
15.5-24.5	1/10	LS	.05			
245-30.0	1/10	55	.03			
30.0-34.5	10/10	10	.07			
34.5-39.5	10/10	10	.01			
39.5-44.0	10/10	1 C	.001			

1553 (2/77)

Figure 3-4 LWC Assessment Sheet

#### 4. REFERENCES

- Borovikov, A.M., A.K. Khrgian et al (1961): Fizika Oblakov (cloud physics) Gidrometeor, Izdatel'stvo, Leningrad (English translation by Israel Program for Scientific Translations, Jerusalem, 1963), 91, 92, 93, 98, 103, 104.
- U.S. Department of Commerce, U.S. Department of Defense, U.S. Department of Transportation (1969): Federal Meteorological Handbook No.2 Synoptic Code, Washington, D.C.
- Feteris, P.J., A.S. Lisa, and A.J. Bussey (1975): Environmental Definition Program Cross-Sectional Analysis; Summary of Data and Analysis Techniques, AFCRL-TR-76-002, Final Report, Air Force Cambridge Research Laboratories, Hanscom AFB, Massachusetts.

5. APPENDIX A

OU de promion (set le 279) les est fils for les fils le 177 et 200 fils et 187 et 200 fils et 200 fils

Table A-1 Water Content of Different Parts of a Cumulus Cloud

/ater	ir.				Cloud	Cloud Thickness (km)	s (km)			
CC. 3	tent	0.5-	1.5	2.0	2.5	3.0	3.0-	3.5-	4.5	5.0
M	CP.	0.29	0.41	0.57	08.0	0.86	0.97	1.20	1.28	1.46
W	l m	0.37	0.59	0.83	1.10	1.18	1.31	1.75	1.76	1.90
M	7	0.53	0.98	1.43	1.90	2.08	2.39	3.14	3.02	3.33
WCP	ā	0.27	0.37	0.49		0. 79	0.89	1.11	1.53	1. 52
M		0.33	0.50	0.68	0	1.14	1.30	1.47	1.93	2.20
WM	,	0.43	0.86	1.15	1.71	2.16	2.47	2. 90	3.59	
W	ď	0.27	0.26	0.30	0.40	0.47	0.64	0.68	0.68	1.51
WE		0.30	0.35	0.38	0.55	0.67	0.89	1.00	1.02	2.17
WM	¥	0.39	0.48	0.56	0.85	1.10	1.64	2. 23	2.00	3.28
WCP	Ġ.	0.27	0.36	0.53		0.80	0.89	1.11	1.35	1.50
IN I		0.34	0.51	0.75	1.00	1.14	1.25	1.53	1.75	2.15
B	7	0.45	0.84	1.28	1.77	2.07	2.35	2.93	3.21	3.99
				•		Dill Mo				

[Ref: Statskiy (1969)]

Table A-2 Average Values of Water Content in Different Parts of a Cumulus Cloud

Part of Cloud	w	ater Content (g/r	n <sup>3</sup> )
(by thirds)	W <sub>CP</sub>	$\overline{\mathbf{w}}_{\mathbf{n}}$	$\overline{\mathbf{w}}_{\mathbf{M}}$
Upper	0.73	1.02	1.78
Middle	0.66	0.93	1.70
Lower	0.45	0.61	1. 04

[Ref: Skatskiy (1969)]

The mean liquid water content averaged in a horizontal plane is represented by  $\overline{W}_{CP}$ , Similarly  $\overline{W}_B$  represents the mean liquid water content in the updrafts and  $\overline{W}_M$  represents the mean of the maximum values.

Table A-3 The Average Characteristics and Liquid Water Content of Various Types of Frontal Clouds

Cloud Characteristics		Liquid-	-water Cor g/m <sup>3</sup>	Nun	Number		
Туре	Cloud Thick- ness	Temp.	Mean	Maxi-	Mini- mum	Sound- ings	Measur
		War	m half o	f the year		E CALLED	161
Ns	1174	2. 9	0.28	0.64	0.09	15	126
Ns-As	1616	-2.1	0.34	0.68	0.09	10	72
As	1259	-3.5	0.21	0.50	0.01	6	43
Ac	543	-1.9	0.13	0.38	0.01	23	97
Sc	717	4.4	0.25	0.50	0.04	- 11	64
St .	512	8.4	0.27	0.63	0.11	6	35
		Col	ld half o	f the year		•	1000
Ns	1002	-3.7	0.19	0.55	0.06	25	162
Ns-As	1344	-6.0	0.12	0.14	0.06	2	17
As	862	-5.4	0.07	0.26	0.03	7	26
Ac	481	-5.8	0.07	0.15	0.04	5	17
Sc	377	-3.4	0.16	0.32	0.03	11	40
St	623	-1.2	0.23	0.33	0.07	8	36

[Ref: Ponomarenko and Zabolotskaia (1965)]

TABLE A-4
WATER CONTENT IN CUMULUS CONGESTUS CLOUDS

Height above cloud bottom	Voit 1965	Nikandrova & Chuvaev	Chuvaev & Kriukova 1954
(m)	Averag	ge Water Content (	g/m <sup>3</sup> )
51-450	0.14	0.35	0.35
451-850	0.42	0. 56	0.59
851-1250	0.72	0. 79	0.74
1251-1650	1. 03	0. 97	0.97
1651-2050	1. 30	1.02	0. 98
2051-2500	1.48	1.02	1.01
2501-3000	1. 60	1.06	1.04
3001-3500	1.38	0. 98	0.99
η(g/cm <sup>2</sup> )	0.36	0. 30	0. 29
Average	1.49	. 78	. 77

TABLE A-5

FREQUENCY OF VALUES OF WATER CONTENT AS A FUNCTION OF

TEMPERATURE (%) FOR STRATOCUMULUS, STRATUS, AND ALTOCUMULUS CLOUDS

Clouds Sc, St, Ac Interval of temperature (in degrees) -20.1 5 15.0 - 19.9 Water content 5.0 - 9.9 .25.0, .10.0 20.0 g /m3 0.0-4 23.6 < 0.05 29.3 16.1 10.6 6.0 4.8 4.2 0.05 -0.10 29.3 35.0 30.3 28.9 23.2 17.4 15.7 12,2 0.11 -0.15 25.9 13.2 2.14 20.0 11.4 16.7 13.4 11.8 9.4 0.16 -0.20 9.8 3.4 12.6 14.6 14.5 11.9 10.6 18.9 20.0 0.21 -0.25 3.4 7.5 5.3 10.6 10.4 9.7 11.8 14.1 13.33 5.7 0.26 -0.30 5.3 13.33 5.9 8.5 7.2 7.3 8.2 9.2 0.31 -0.35 1.7 3.4 3.3 6.0 6.0 7.2 6.5 6.6 0.36 -0.40 1.7 0.6 1.8 7.2 6.6 3.8 3.7 0.6 0.41 -0.45 1.4 3.7 13.33 4.2 5.7 2.8 3.0 0.46 -0.50 0.6 0.7 1.7 1.9 3.8 2.0 5.8 20.0 0.51 -0.55 0.3 1.2 1.9 2.5 2.9 0.9 0.56 -0.60 0.7 2.3 1.6 1.9 0.2 1.7 0.61 -0.65 0.1 0.6 1.0 1,2 2.6 0.66 - 0.70 0.1 0.5 0.5 2.0 0.9 0.71 -0.75 0.2 0.6 1.0 2.3 0.76 -0.80 0.09 0.9 1.1 1.3 0.9 0.81 -0.85 0.09 0.07 1.0 1.5 0.86 - 0.90 0.13 0.15 1.3 0.9 0.91 -0.95 0.1 0.19 0.3 0.96 - 1.000.1 0.09 0.2 0.3 0.6 1.01 - 1.05 0.9 0.07 0.6 0.6 1.06 - 1.10 0.3 1.11 - 1.15 0.33 0.6 1.16 - 1.20 0.07 0.9 0.3 1.26 - 1.30 0.33 1.51 -1.55 0.07 0.15 1.56 - 1.60 0.33 >1.60 0.5 1.0

58

No. of cases

174

701

1240

1484

649

[Ref: "cloud Physics"-Borovikov, etc.]

306

106

15

TABLE A-6
FREQUENCY OF VALUES OF WATER CONTENT AS A FUNCTION OF
TEMPERATURE (%) FOR STRATOCUMULUS CLOUDS

				Interval o	f tempera	ture (in d	egrees)		
Water content g/m <sup>3</sup>	-25.0, -20,1	-20.0, -15.1	-15.0, -10.1	-10.0, -5.1	-5.0, -0.1	6.4-0.0	5.0 – 9.9	10.0 – 14.9	15.0 - 19.9
< 0.05	16.7	22.5	14.5	9.2	6.0	4.9	3.8	6.3	
0.05-0.10	47.7	33.75	28.6	26.1	21.4	17.0	16.2	13.9	
0.11-0.15	33.3	17.5	23.1	17.9	18.0	14.4	11.5	11.4	20 2
0.10-0.20		11.25	13.6	13.9	13.9	10.5	11.9	17.7	75.
0.21-0.25	8.3	7.5	4.8	10.3	10.6	10.2	9.8	7.6	
0.26-0.30		3.75	5.3	6.1	8.2	8.8	8.1	7.6	II I
0.31-0.35		1.25	4.0	5.8	5.2	6.8	5.1	6.3	B
0.36-0,40			2.0	3.4	4.1	4.7	6.4	7.6	
0.41-0.45		1.25	1.5	2.9	3.0	3.3	4.3	6.3	
0.46-0.50		1.25	0.9	1.5	1.9	3.0	2.1	6.3	25
0.51-0.55			0.4	1.2	1.9	3.0	3.0	1.3	1
0.56-0.60			0.9	0.2	1.5	2.1	2.1	2.5	-
0.61-0.65			0.2	0.6	1.0	1.4	3.0		
0.66-0.70		11 1	0.2	0.2	0.8	1.2	2.1		111
0.71-0.75				0.4	0.8	2.1	1.3		
0.76-0.80				0.1	1.0	1.2	1.7	1.3	
0.81-0.85						1.4	1.3		
0.86-0.90				0.1		0.2	1.7	1.3	
0.91-0.95					0.1	0.2			
0.96-1.00				0.1	0.3	0.5	0.8	1.3	No.
1.01-1.05		ARTE TO THE			0.1	0.8	0.8		
1.06-1.10						0.2	*		
1.11-1.15				N. P.	Land Section	0.9	0.4		
1.16-1.20		7			0.1	0.2		0.3	
1.26-1.30							0.4		
1.51-1.55		P. 1			0.1	0.2			
1.56-1.60							0.4	9	
>1.60				1		0.8	1.3		
No. of cases	12	80	455	855	785	429	234	79	4

[Ref: "Cloud Physics"-Borovikov, etc.]

TABLE A-7
FREQUENCY OF VALUES OF WATER CONTENT AS A FUNCTION OF
TEMPERATURE (%) FOR NIMBOSTRATUS AND ALTOSTRATUS CLOUDS

CI	 N.	_	Λ.

				is Ns - As					
			Interval of temperature (in degrees)			r -			
Water content 8 / m <sup>3</sup>	-25.0, -20.1	-20.0, -15.1	-15.0, -10.1	-16.0, -5.1	-5.0, -0.1	0.0 - 4.9	6.6 - 0.3	10.0 – 14.9	6.61 - 0.51
< 0.05	0.7	11.5	5,2	8.8	3.5	0.3	2.3	9.5	
0.05 -0.10	26.1	24.6	31.0	20.3	23.3	12.2	12.7	9.5	
0.11 -0.15	26.1	24.6	18.4	20.3	15.1	13.8	5.7	4.8	1.
0.16 - 0.20	13.1	9.9	17.2	16.3	13.1	11.3	12.7	14.3	
0.21 -0.25	4.3	11.5	12,1	13.4	11.0	11.3	10,3	9.5	
0.26 - 0.30	17.4	8.2	2.9	6.2	10.4	8.4	16.2	19.0	11-11
0.31 -0.35	4.3	1.6	6.3	5.9	8.3	10.9	5.7	14.3	1
0.36 - 0.40		4.9	1,1	2.9	4.3	6.1	3.4	400	
0.41 - 0.45		1,6	2,9	3.4	2.5	6.1	6.9	4.8	200
0.46 - 0.50		1.6	1.1	0.3	1.3	5.1	8.0	4.8	1
0.51 - 0.55			0.6	1.3	2.3	3.2	2.3		1031
0.56 - 0.60			0,6	0.6	1.2	3.9	2,3		1814
0.61 -0.65					0.8	1.3	1.15	4.8	1
0.66 - 0.70			0.6		0.3	1.6	4.6	800	PAGE.
0.71 -0.75				0.3	0.8	2.3	1.15		
0.76 - 0.80	97.5				0.5	1.0	1.15		
0.81 -0.85	Marks 1				0.5	0.3	1.15		
0.86- 0.90	tate :					0.3			
0.91 -0.95					0.2				
0.96 - 1.00						0.3			
1.01 - 1.05					0.2				
1.06 - 1.10					0.2	0.3		4.7	
1.11 - 1.15					0.2		1.15		
1.26 - 1.30	- Maria						1.15		
No. of cases	23	61	174	306	604	311	87	21	

[Ref: "Cloud Physics"—Borovikov, etc.]

TABLE A-8 AVERAGE WATER CONTENT  $(GM/M^3)$  AS A FUNCTION OF HEIGHT ABOVE THE BASE FOR CUMULUS CLOUDS

Height of middle layer above cloud base (m)	med.	and Cu	content cong. c	louds	Average conter den	nt of	Average conten	t of	H (m)	Average conten	t of
I SP			periphery		Cu cong.					Cu cong.	
Heigh layer base (	•	•			v	n	w	•	Average	w	
25	0.09	42			0.10	9	0.08	8	25	0.10	18
150	0.23	116	0.12	6	0.33	16	0.17	35	250	0.35	48
350	0.31	127	0.16	10	0.38	23	0.33	37			
550	0.54	104	0.27	6	0.85	29	0.38	2	650	0.59	41
750	0.56	81	0.13	9	1.06	27	1000				
950	0.86	43	0.31	2	1.70	17				120	
1150	0.76	33			0.89	20	24		1050	0.74	52
1350	0.69	25	0.15	2	0.89	16					1
1550	0.53	19			0.77	3			1450	0.97	54
1750	0.52	7			0.81	2			1850	0.98	71
1000		18 2 1							2250	1.01	75
									2750	1.04	37
		301							3250	0.99	21
10143	3.4								3750	0.34	5

[Ref: "Cloud Physics"-Borovikov, etc.]

	Temperature (in degrees)								
Height of middle layer (m)	<-	10	-10	-0	>0				
	W	n	w	n	W	n			
53	0.14	73	0.15	367	0.19	101			
150	0.16	35	0.19	199	0.22	51			
250	0.19	25	0.25	132	0.40	33			
350	0.18	16	0.27	109	0.35	21			
450	0.23	9	0.32	57	0.34	13			
550	0.26	4	0.29	32	0.33	10			
650	0.23	3	0.32	17	0.48	4			
750	0.11	5	0.34	16	0.55	3			
850	0.04	1	0.26	8					
950	0.06	1	0.16	3					
1050	0.62	1	0.18	2					
1150					0.22	1			
1250	0.57	1							
1350					0.09	1			
1450					0.70	1			

[Ref: "Cloud Physics"—Borovikov, etc.]

Height of middle layer (m)	Temperature (in degrees)									
	<-10		-10	)-()	>0					
	w		w	п	W'	n				
50	0.19	20	0.16	68	0.27	47				
150	0.20	12	0.21	40	0.24	18				
250	0.225	8	0.15	37	0.28	22				
350	0.16	13	0.19	37	0.29	19				
450	0.11	11	0.21	46	0.43	17				
550	0.20	4	0.23	41	0.49	12				
650	0.23	5	0.18	28	0.38	10				
750	0.06*	1	0.21	38	0.35	12				
850	0.16*	1	0.16	25	0.41	9				
950	0.20	9	0.27	16	0.39	5				
1050	0.20	3	0.20	25	0.50	8				
1150	0.15	5	0.31	12	0.38	3				
1250	0.12	2	0.25	9	0.27	7				
1350	0.10	4	0.27	11	0.50	3				
1450	0.35	2	0.32	12	0.20*	1				
1550	0.02*	1	0.24	11	0.24	3				
1650	0.12	2	0.23	10	0.25	3				
1750	0.10	2	0.28	5	0.16	3				
1850	0.12	2	0.33	3	0.37	4				
1950	0.22	3	0.24	6						

[Ref: "Cloud Physics"-Borovikov, etc.]

6. APPENDIX B

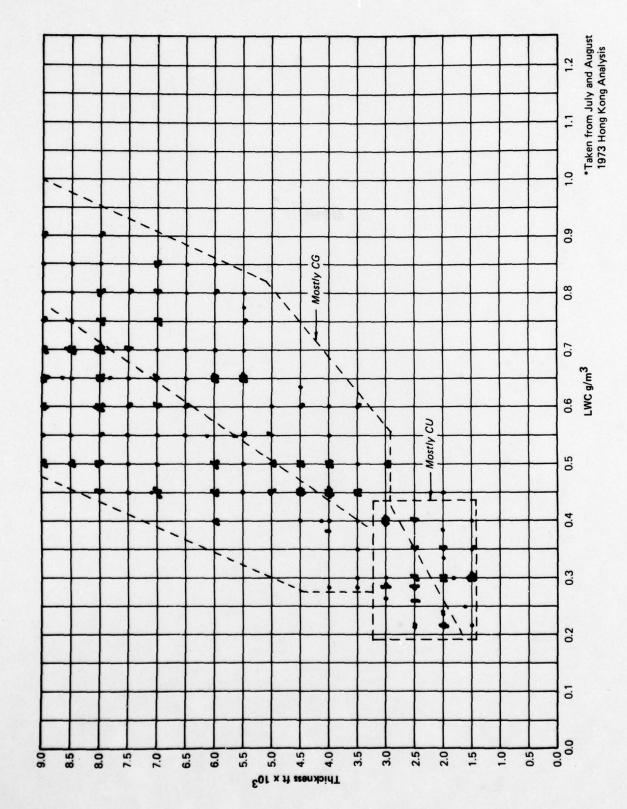


Figure B-1 LWC Assessed for Cumulus and Camula Congestus Clouds

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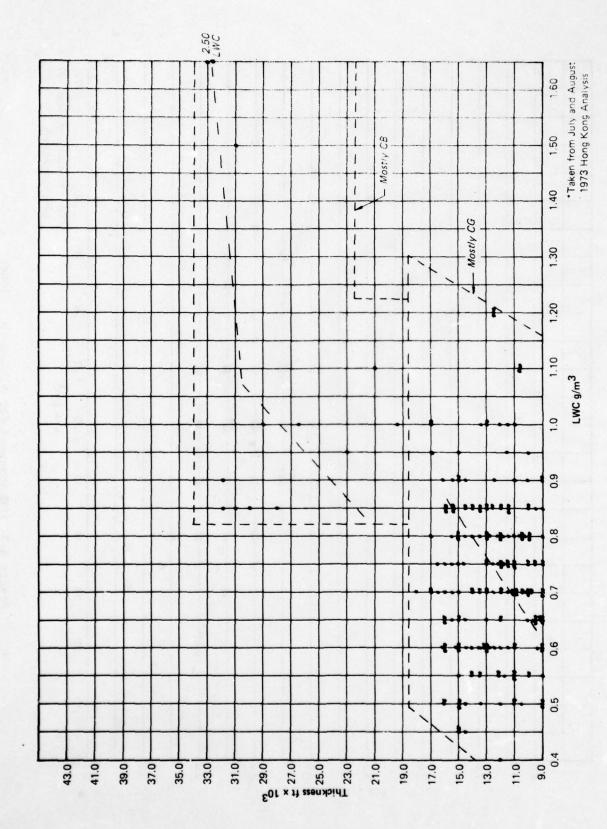


Figure B-2 LWC Assessed for Cumulus and Congestus and Cumulonimbus Clouds

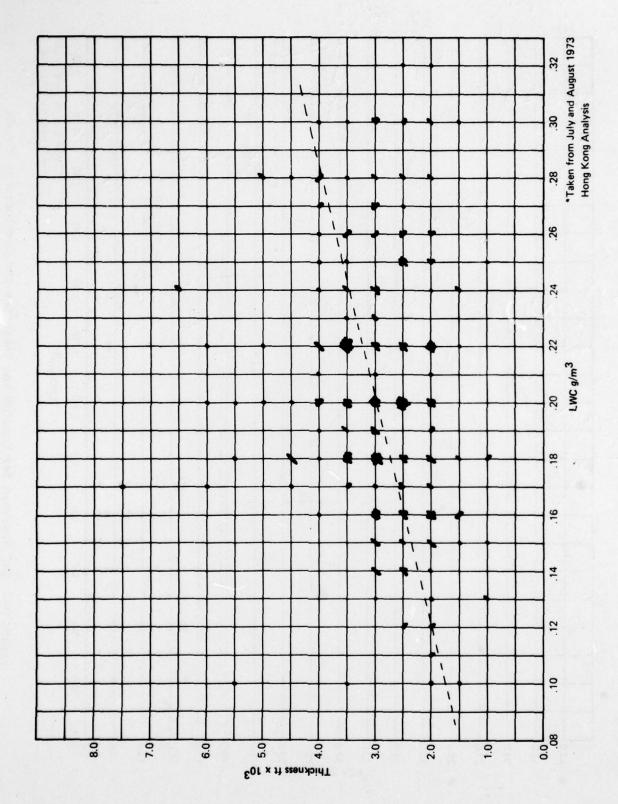


Figure B-3 LWC Assessed for Altocummulus Clouds

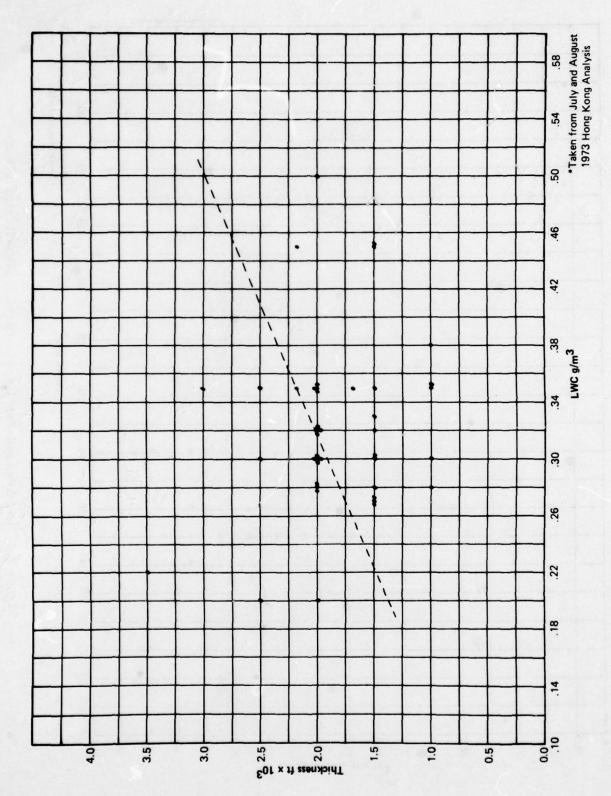


Figure B-4 LWC Assessed for Stratocumulus Clouds

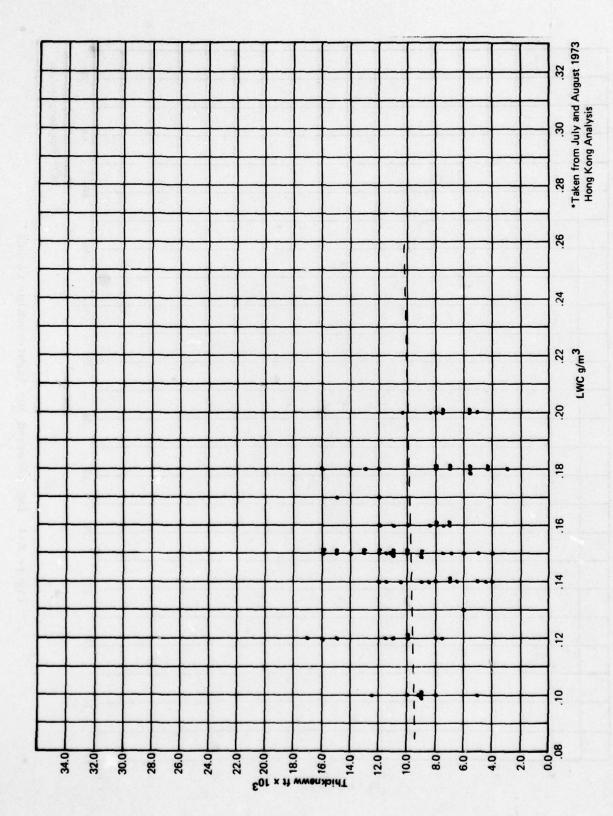


Figure B-5 LWC Assessed for Altostratus and Nimbostratus Clouds